J. Dairy Sci. 84:2560–2572

Economic and Environmental Impact of Four Levels of Concentrate Supplementation in Grazing Dairy Herds

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ABSTRACT

Low-cost, pasture-based forage systems are a viable management alternative for small to moderately sized dairy farms in the Northeast United States. A whole farm analysis was conducted to evaluate the potential long-term environmental impact and economic benefit of varying the level of concentrate supplementation on seasonal grazing dairies. A representative dairy farm was simulated with various production strategies over 25 yr of historical Pennsylvania weather using the Dairy Forage System Model. A representative grazing farm (81 ha) was simulated with four levels of daily concentrate supplementation: 1) no supplement, 2) 3 kg of DM/cow in early lactation, 3) 6 kg of DM/cow in early lactation, and 4) 9 kg of DM/cow in early lactation fed daily to the lactating cows to meet annual milk production levels of 5000, 6068, 6968, and 7700 kg/cow, respectively. These farm systems were then compared to an alfalfa- and corn-based confinement system on the same land base where total mixed rations were fed to maintain an annual milk production level of 9000 kg/cow. The five systems were simulated for three scenarios. In the first, total milk sold per farm (625,000 kg) was similar across all systems. In the second, cow numbers were held constant across all systems (100 mature cows), and total milk sold per farm varied. In the third, stocking rate was set so that forage consumed equaled forage production on the farm. Profitability increased as supplementation level increased in the grazing systems, but at a decreasing rate with each successive level of supplementation. At higher levels of supplementation, the grazing dairy farms showed greater profitability than the confinement systems. Economic risk or year-to-year variation also decreased as concentrate supplementation level increased. The grazing systems showed an environmental benefit compared with the confinement systems by decreasing nitrogen leaching losses. Concentrate supplementation of grazing lactating dairy cows provided an increase in profitability and a mixed impact on nutrient balance of the farm.
(**Key words:** economic, grazing, model, supplementation)

Abbreviation key: CNCPS = Cornell Net Carbohydrate and Protein System, **CONF** = confinement, **DAFOSYM** = Dairy Forage System Model, **FU** = fill unit; **HI** = 9 kg DM/cow maximum supplement; **LOW** = 3 kg DM/cow maximum supplement, **MED** = 6 kg DM/cow maximum supplement; **NONE** = no supplement.

INTRODUCTION

Due to relatively unstable and low milk prices and increasing input costs, dairy farmers are searching for ways to decrease input costs, particularly feed expenses. Well-managed grazing systems offer an opportunity to reduce the cost of producing forage during the grazing season for small to moderately sized dairy farms in the Northeast United States. Buttel et al. (2000) reported that 23% of all dairy farms in Wisconsin are utilizing some type of management-intensive rotational grazing. When properly managed, pasture is high in nutritive value compared with other forage crops. Studies have indicated that the use of pasture can increase net returns from $85 to $168 per cow (Dartt et al., 1999; Parker et al., 1992) predominantly due to a decrease in feed harvest and handling costs.

When high quality pasture is available in adequate quantities, metabolizable energy is the most limiting factor for milk production (Kolver and Muller, 1998; Kolver et al., 1998). Research has shown that properly managed pasture can support 18 to 30 kg of milk without supplemental concentrate (Kolver and Muller, 1998; Mayne, 1996); supporting research has demonstrated a positive response in milk production to concentrate supplementation (Bernard and Carlisle, 1999; Polan et al., 1986).

The marginal response of increased milk production per unit of concentrate fed appears to follow the law of diminishing returns, in that after a certain supplementation level, each additional unit of supplement will result in a less than one unit increase in milk production

Received February 8, 2001.
Accepted June 18, 2001.
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(Polan, 2000; Reis and Combs, 2000). Therefore, maximum supplementation levels may or may not result in maximum profitability. Although research has been conducted to determine the optimal level of supplementation of grazing dairy cows (Polan, 2000; Soriano et al., 2000), the whole farm environmental and economic impact of purchasing and feeding various levels of concentrate to a grazing dairy herd has not been characterized.

To evaluate the economic and environmental impact of feed management decisions such as the level of supplement, a comprehensive, multidisciplinary systems approach is required. Effects on all major farm components and their interactions must be considered. Such an analysis requires computer modeling as an integration tool. The Dairy Forage System Model (**DAFOSYM**) provides a comprehensive simulation model that integrates the many biological and physical processes on the farm. Crop growth, harvest, storage, feeding, animal performance, and manure handling are simulated over many weather years to investigate the whole farm impact of strategic management decisions (Rotz et al., 1989, 1999b). Therefore, the objective of this study was to simulate the effects of varying the level of concentrate supplementation in a well-managed rotational grazing system on productivity, profitability, and environmental impact of a representative Pennsylvania dairy farm.

MATERIALS AND METHODS

Several tasks were required to complete this study. The first was to adapt and verify the animal submodel of DAFOSYM to simulate a grazing dairy herd with limited concentrate feeding. The revised model was then used to compare production systems on a representative grazing dairy farm, while altering the amount of concentrate fed to the lactating herd. Finally, the interaction of these results with other farm characteristics and management strategies was determined through a sensitivity analysis.

Model Description and Development

The DAFOSYM model is a whole farm model where crop production, feed use, the return of manure nutrients back to the land, production costs, income, and net return or profit of representative farms are simulated over many years of weather (Rotz et al., 1989, 1999b). Growth and development of alfalfa (*Medicago sativa*), grass (cool season), corn (*Zea mays*), and other crops are predicted on a daily time step from soil and weather conditions. Tillage, planting, harvesting, and storage components predict resource use, timeliness of operations, crop losses, and nutritive changes in feeds. Feed allocation and animal response are related to the nutritive value of available feeds and the nutrient requirements of six animal groups making up the dairy herd (Rotz et al., 1999a). Nutrient flows through the farm are modeled to predict potential nutrient accumulation (P and K) and N volatilization and leaching losses to the environment (Rotz et al., 1999b).

Table 1. Nutrient composition of pasture used in the simulations.

Month	CP (% DM)	RUP (% CP)	NE_L (Mcal/kg)	NDF (% DM)
April–May	24	25	1.60	52
June	22	25	1.55	53
July–August	20	25	1.52	55
September–October	24	25	1.57	53

Simulated performance is used to predict production costs, income, and net return or profit of representative farms for each weather year. A simple whole farm budget is used where investments in equipment and structures are depreciated over their economic life and annual expenditures and incomes are accounted. Possible government subsidies and income tax implications are not considered. By modeling several alternatives, the effects of system changes are compared including resource use, production efficiency, environmental impact, and profitability. The variation in annual values can then be used to assess the risk involved in alternative technologies or strategies as weather conditions vary.

For this study, pasture production was simulated as a cool-season grass using functions from the GRASIM model developed and validated by Mohtar et al. (1997). This mechanistic model simulated photosynthetic rate and carbohydrate production as a function of solar radiation level, day length, ambient temperature, atmospheric CO_2 level, and crop leaf area. Nutritive content of pasture was set to represent typical cool-season grass pasture in the Northeast (Fales et al., 1995). Nutritive characteristics (CP, RUP, NE_L, and NDF concentrations) varied to reflect a decrease in quality during the middle of the grazing season (Table 1). They were not influenced directly by weather, i.e., they were the same during each simulated year. The RUP levels were slightly higher than values found in typical Northeastern pastures. This change was made to account for the lower efficiency of N utilization in the rumen by grazing dairy cows (Berzaghi et al., 1996; Holden et al., 1994b).

Within DAFOSYM, an animal submodel predicts the performance of a dairy herd consisting of growing heifers, lactating cows, and nonlactating cows (Rotz et al., 1999a). This submodel was originally designed to simulate animals fed a TMR to meet their nutrient needs. To model grazing dairy herds under low levels of concentrate feeding, two modifications were made to the prediction of DMI.

First, pasture consumption can affect DMI by increasing digestibility and passage rate (Holden et al., 1994b; Kolver and Muller, 1998). In the original DAFOSYM animal submodel, a theoretical fill unit (**FU**) was defined as a weighting factor for increasing or decreasing the effect that the NDF in feed particle size pools had on rumen fill (Rotz et al., 1999a). These FU reflected the relative rate of fiber digestibility compared with that in other feeds. To better reflect the greater rates of passage for pasture diets, fill factors for the large and small particle pools of pasture forage were reduced from the original values of 1.4 and 0.5 to 1.0 and 0.4, respectively.

In the original model, DMI was limited by either the energy or fiber consumed, whichever was first limiting. The animal could not consume more energy than was required, and the effective fiber consumed could not exceed a fiber intake capacity. This maximum fiber consumption expressed in fill units [FU/(kg of BW)/d] varied depending on stage of lactation, peaking at approximately 1.3% of BW for multiparous cows (Rotz et al., 1999a). However, pasture NDF intakes of 1.5 to 1.75% BW are reported (Bargo et al., 2000; Kolver and Muller, 1998), suggesting that NDF of high quality pasture may have less effect on fill than stored forages. For this study, the maximum constraint or limit on fiber intake was removed. Thus, intake was solely controlled by the energy constraint, allowing lactating animals to consume as much feed as needed to meet the energy required for a set milk production level.

Model Evaluation

To verify these changes in the model, several DAFOSYM simulations were done with grazing dairy cows fed various levels of supplementation. The DMI and milk production responses generated by DAFOSYM were compared to those predicted by the Cornell Net Carbohydrate and Protein System (**CNCPS**) version 4.0 (Fox et al., 1992) and the SPARTAN Dairy Ration Evaluator/Balancer Version 2.01 (1992) at three stages of lactation and under similar feeding conditions.

For further verification, experimental data involving pastured dairy cows were summarized and compared with the model predicted responses. Studies were selected based on sufficient data defining DMI, BW, DIM, milk production and composition, and feed composition. Studies represented data from Australia (Grainger and Mathews, 1989; Robaina et al., 1998), New Zealand (Carruthers and Bryant, 1983; Kolver et al., 1999, 2000; Mackle et al., 1997), Northern Ireland (Mayne et al., 1988), and the United States (Berzaghi et al., 1996; Holden et al., 1994a, 1995; Kolver and Muller, 1998; Rippel, 1995).

Representative Farms

The effect of varying the level of concentrate supplementation was evaluated on a spring-calving dairy farm representative of an actual low-input grazing operation found in central Pennsylvania. This grazing farm was then compared with a more traditional confinement (**CONF**) operation of similar land area, soil type, and cow numbers. The modeled farms represented well-managed operations of the region. The soil was assumed to be a somewhat marginal, shallow loam soil (available water holding capacity of 80 mm). Simulations were done for 25 weather yr with actual State College, Pennsylvania, weather data from 1974 through 1998. Phosphorus feeding levels were set at 120% of NRC (National Research Council, 1989) guidelines to reflect typical P feeding levels of many dairies (Wu et al., 2000).

The grazing farm represented the use of rotational grazing where animals were maintained on pasture year round and seasonally calved in the spring. This strategy minimized the cost of housing for mature animals and greatly reduced manure handling over a more traditional, confined operation. Heifer housing costs were also decreased, as heifers were housed in calf hutches until they were moved to open lots (winter) or pastures. All 81 ha were seeded as perennial orchardgrass (*Dactulis glomerata* L.) pastures. Excess pasture in the spring and summer was harvested as baled silage or dry hay, and the animals were supplemented with hay or silage in the winter months and when pasture availability was limited. A spring calving cycle was used in which all cows were dry during the winter months, with peak milk production in the late spring. Culling rate was assumed to be 35%, which included the culling of bred, productive animals that did not calve within the spring calving window required to maintain the seasonality of the herd. This resulted in a higher average cull price of $1.10/kg.

The confined farm used a more traditional CONF system (no pasture) on dairy farms in this area. Approximately half the farm was seeded in alfalfa with the remainder in corn. First, third, and fourth cuttings of alfalfa were harvested and chopped as silage with the second cutting harvested as dry hay. Most of the corn was harvested and stored as silage, but on good growing years some of the corn was custom harvested as dry grain. All silage was stored in bags. The herd was fed rations consisting of available hay, silages, grain, and protein supplements blended to meet requirements. The number of cows in the herd varied depending on whether cow numbers or total milk sold was held constant across farms, but milk production per cow remained constant at 9000 kg/cow annually. The culling rate of the herd was 35%, but in this case culled animals did not include productive animals, therefore the selling price was lower ($0.66/kg). Grain harvest was custom hired at a rate of $64.25/ha.

Machinery and facility requirements varied between the grazing and CONF farm systems as listed in Table 2. A few other parameters also varied between the systems. In the grazing system, tilling and planting was custom hired at a rate of $99/ha. Nitrogen fertilizer use for the two options was 112 kg/ha (pasture) and 112 kg/ha (corn), respectively. Labor requirements for milking and animal handling were set at 3 min/cow per day. A double-eight parlor was used in both the grazing and CONF systems. For the grazing system, 12 h/wk of labor was assigned for pasture management, i.e., movement of animals, fence, water, etc.

Prices were set to reflect long-term relative values of farm inputs and outputs in current markets (Table 3). A real interest rate (approximately nominal rate minus inflation) was assumed on investments. Milk prices were held constant between management systems, i.e., no premiums or other price bonuses were included for potential differences in milk quality among the systems. Property tax was charged at 2.5% of the estimated assessed value of the property. Property tax was not included on land, but an annual land charge of $124/ha was included.

Feeding Comparisons

Various simulations were run to determine the impact of system changes and level of concentrate supplementation on feed production, feed use, milk production, manure production, nutrient losses, production costs, and farm net return. Concentrate was supplemented throughout the lactation, fed at 100% of maximum level in early lactation, 70% of maximum level in midlactation, and 30% of maximum level in late lacta-

Table 2. Machines and structures used for the analysis of the grazing and confinement dairy farm systems.

	Grazing farm			Confinement farm		
Machine or storage type	Size	No.	Initial cost ($)	Size	No.	Initial cost ($)
Tractors	35 kW, used	1	10,000	35 kW, used	1	10,000
	65 kW	1	34,800	65 kW	1	34,800
	...	...	...	80 kW	1	53,100
Mower-conditioner	2.7 m	1	23,900	2.7 m	1	23,900
Hay rake	2.7 m	1	5200	2.7 m	1	5200
Round baler	Large, 6.0 t DM/h	1	24,300	Large, 6.0 t DM/h	1	24,300
Bale wagon	5.0 t	1	4500	5.0 t	1	4500
Bale wrapper	Large	1	17,100	...	...	...
Forage harvester	...	...	...	Medium, 12 t DM/h	1	18,900
Forage wagons	...	...	...	6 t	2	10,200
Feeder mixer wagon	...	...	...	Medium, 8.5 t	1	18,900
Manure pump/agitator	450 t/h	1	10,000	450 t/h	1	10,000
Manure spreader	Small V tank (6 t)	1	8400	Lg. V tank (10.9 t)	1	21,400
Coulter-chisel plow	...	...	...	2.7 m	1	8500
Tandem disk harrow	...	...	...	3.7 m	1	7600
Field cultivator	...	...	...	4.9 m	1	8000
Row crop planter	...	...	...	6 row	1	18,000
Grain drill	...	...	...	2.4 m	1	7200
Hay shed	100 t	1	10,000	100 t	1	10,000
Silage bagger	...	...	...	Lg (20 t DM/h)	1	24,500
Manure storage	15 × 4.5 m	1	29,212	38 × 4 m	1	50,500
Machinery shed	...	1	30,000	...	1	60,000
Milking center	Double eight	1	200,000	Double eight	1	200,000
Open lot housing		1	8750		...	...
Freestall barn	...	...	...	...	1	85,000
Replacement housing	...	1	22,820[1]	...	1	47,750[3]
Commodity storage	...	1	3900[2]	...	1	7000[3]
Pasture fence & water	...	1	29,500	...	...	...

[1]Calf and heifer housing consists of calf hutches and open lot in the grazing systems, which varied with lactating cow numbers as follows: 125 cows = $21,080, 10 cows = $18,190, 90 cows = $15,840, and 81 cows = $14,430.

[2]Commodity storage space varied in the grazing systems with supplementation level as follows: NONE (no supplement) = $0.00, LOW (3 kg of DM/cow maximum supplement) = $752, MED (6 kg of DM/cow maximum supplement) = $1505, and HI (9 kg of DM/cow maximum supplement) = $2280.

[3]In the confinement systems, calves and heifers were housed in barns with pens and free-stall barns, which were less flexible and therefore value was held constant. Commodity storage was also fixed.

Table 3. Economic parameters and prices assumed for various system inputs and outputs for the analysis of the representative dairy farms. Prices were set to represent long-term relative prices in current value, which were not necessarily current prices.

Parameter	Value	Parameter	Value
Milk price	$32/hL	Selling price of feeds/animals	
Milk marketing and hauling fees	$2.28/hL	Alfalfa	$121/t DM
Labor wage rate	$9.35/h	Corn silage	$72/t DM
Custom tillage and planting	$99/ha	Corn grain	$116/t DM
Custom grain harvest	$64.25/ha	Cull cow[1]	$0.66/kg
Livestock expenses[2]		Heifer	$1,200/animal
Veterinary and medicine	$80/cow	Calf	$20/animal
Semen and breeding	$40/cow	Buying price of feeds/bedding	
Animal and milking supplies	$25/cow	Concentrate mix	$132/t DM
Insurance on animals	$10/cow	Alfalfa hay	$138/t DM
Utilities for milking and animal handling	$60/cow	Soybean meal	$254/t DM
		Protein mix	$395/t DM
Animal hauling	$5/cow	Mineral/vitamin mix	$435/t DM
DHIA, registration, etc.	$23/cow	Straw bedding	$66/t DM
Annual cost of seed and chemical		Fertilizer prices	
New forage	$203/ha	N	$0.35/kg
Established forage	$15/ha	P	$0.44/kg
		K	$0.27/kg

[1]For grazing systems, the average cull price is higher ($1.10/kg) than typical cull cow prices to account for the sale of productive, bred cows that do not meet the calving window required to maintain a seasonal calving herd.

[2]Source- Dairy Farm Business Summary-Intensive Grazing Farms New York (Conneman et al., 2000).

tion. Maximum daily concentrate levels allowed in each situation were: **NONE** = no supplement, **LOW** = 3 kg of DM/cow, **MED** = 6 kg of DM/cow, and **HI** = 9 kg of DM/cow. The nutritive value of the concentrate supplement (15% CP, 10% NDF, 1.96 Mcal/kg of NE_L) for the grazing systems was the same for all levels of feeding. Annual milk production was set at 5000, 6068, 6968, and 7700 per cow for the four supplement levels, respectively. These milk production levels were established with existing data from similar supplementation and grazing strategies.

The grazing farm was then compared with the CONF farm where animals were fed a TMR to maintain an annual milk production of 9000 kg per cow. The diet for the CONF herd was based on feeds available on the farm, as well as any additional purchased feed required to meet nutrient requirements.

Three scenarios were simulated for the above farm systems. In the first scenario, total milk sold per farm was held constant (approximately 625,000 kg of milk produced annually on the farm), and animal numbers were adjusted based on feeding strategy and the resulting individual animal milk production to meet that farm production goal. In the second scenario, cow numbers were held constant at 100 mature lactating and dry cows and 74 heifers, and total milk sold per farm was allowed to float according to milk production associated with supplementation levels. In the third scenario, stocking rate on the farm was set so that forage usage matched forage production on the farm, to minimize forage purchased or sold. Pasture area used for spring and summer grazing in each scenario was adjusted to maximize farm profit for the given number of animals. Fall grazing area was assumed to be the entire 81 ha in all grazing systems. All other factors remained the same as the first scenario.

Sensitivity Analysis

A final series of simulations was conducted to measure the influence of various farm characteristics or management changes on the economic benefit (increase or decrease in net return) received from varying levels of concentrate supplementation. All sensitivity analyses were run with annual milk production maintained at approximately 625,000 kg/farm (scenario 1). The grazing systems with NONE and HI concentrate feeding levels and the CONF system were used in these analyses. Independent changes included in the sensitivity analysis were: changing the predominant soil type on the farm from a shallow loam soil to a medium clay loam with greater available water holding capacity (150 mm), increasing milk yield by 10%, increasing concentrate price 20%, and finally increasing breeding costs and culling rate to reflect delayed rebreeding that may occur as a result of low BCS.

RESULTS AND DISCUSSION

Model Evaluation

Before applying the modified dairy herd submodel of DAFOSYM, predicted DMI and milk production values were evaluated to assure that the model adequately represented animal performance under these feeding conditions. First, predictions of DAFOSYM, CNCPS, and the SPARTAN Dairy Ration Evaluator/Balancer were compared for similar animals and feeding conditions. In all 12 simulations, DMI predicted by DAFOSYM was within 8% of that predicted by the other two models (Table 4). Dry matter intakes predicted by DAFOSYM were slightly higher than the other models when no concentrate was supplemented, and slightly lower at high levels of concentrate feeding, but these differences were small.

The DMI and milk production estimates predicted by DAFOSYM were then compared with results from observed experimental data (Table 5). A simple regression was run where DMI responses, as predicted by DAFOSYM, were regressed on the corresponding observed DMI responses to determine the variation (adjusted r^2), precision, and bias (regression coefficient when the intercept was 0) of the relationship. The results are presented in Figure 1. The figure contains the X = Y line (intercept = 0; slope = 1) that would represent perfect agreement between predicted and observed values. The slope of the regression line did not differ significantly from 1, and the model accounted for 88% of the variation in the observed values for DMI. Dry matter intake was slightly overpredicted by DAFOSYM with a bias of 3%. The standard errors of the estimate in the studies of Fox et al. (1992) and Kolver et al. (1998) were slightly higher (1.89 and 1.5 kg of DM/d, respectively) than the standard error in Figure 1 (1.23 kg of DM/d).

Concentrate Supplementation Level

Twenty-five year average performance and economic results include feed production and use, milk production, nutrient losses and accumulation, production costs, and the net return or profit of the farm. The important results to consider are the comparisons between different strategies simulated, not the absolute values generated for any particular farm. Predicted values for a given farm, such as net return, may vary greatly depending upon model assumptions, and thus should not be used to judge the viability of a specific farm. Relative differences between simulated systems, though, provide meaningful evaluation of the effects of system changes. For these reasons, the actual values are reported for the NONE farm, and results from the other farms (LOW, MED, HI, CONF) are reported as differences from the NONE farm values.

Same farm milk output. Long-term (25-yr) simulations show considerable differences in the environmental impact and profitability of the various farm systems. In the first scenario, as level of supplementation increased, thereby increasing milk production per cow, the total number of cows on the farm was decreased to maintain similar total milk sold per farm (Table 6). This decrease in cow numbers, in addition to substitution effects of increasing amounts of supplement, reduced the forage consumed as pasture and increased that harvested as hay or silage on the farm. For the HI farm, forage produced was in excess of forage consumed, and excess forage was sold.

As expected, manure handling decreased as concentrate supplementation increased from NONE to HI due to decreased cow numbers (Table 6). With less manure, N volatilization losses decreased considerably, and N leaching losses decreased by a small amount. Soil P and K accumulation on the farm also decreased with fewer animals to the point where these nutrients were in a long-term deficit at the high supplementation lev-

Table 4. Comparison of milk production and DMI generated by Dairy Forage System Model (DAFOSYM) with those generated by the Cornell Net Carbohydrate and System (CNCPS; Fox et al., 1992) and the SPARTAN Dairy Ration Evaluator/Balancer (1992) for three stages of lactation under different supplementation levels.

DIM	Supplement	Milk yield	DAFOSYM Total DMI	CNCPS Total DMI	SPARTAN Total DMI
	(kg/d)				
60	0	19.0	16.6	16.3	16.5
60	3	23.6	17.7	17.6	17.8
60	6	27.6	18.4	18.6	18.9
60	9	31.3	19.1	19.7	19.7
120	0	17.3	17.6	16.3	17.1
120	3	21.5	18.4	17.5	18.5
120	6	25.1	18.8	18.5	19.4
120	9	28.6	19.1	19.4	20.5
180	0	14.9	16.8	15.7	16.4
180	3	18.5	17.3	16.7	17.5
180	6	21.6	17.6	17.6	18.4
180	9	24.5	17.7	18.4	19.2

Table 5. Summary of select studies reporting DMI and milk production responses to supplementation from grazing studies with lactating dairy cows.

Reference	Stage of lactation[1]	Location[2]	Milk production	Total DMI	Pasture DMI	Supplement DMI
			kg/d			
Rippel, 1995	Mid	US	31.8	18.7	10.5	8.2
Holden et al., 1994a	133 DIM	US	30.5	22.3	15.0	7.3
Holden et al., 1995	133 DIM	US	31.8	21.3	13.6	7.7
Kolver and Muller, 1998	59 DIM	US	29.6	19.0	19.0	0.0
Berzaghi et al., 1996	130 DIM	US	19.5	13.0	13.0	0.0
Grainger and Mathews, 1989	Full	AUS	23.1	15.9	15.9	0.0
			24.0	16.9	13.7	3.2
Robaina et al., 1998	Full	AUS	12.9	14.3	14.3	0.0
			15.7	15.3	13.5	1.8
			16.1	15.5	12.1	3.4
			18.4	17.1	10.4	6.7
Kolver et al., 2000	Full	NZ	14.9	12.9	12.9	0.0
Kolver et al., 1999	48 DIM	NZ	21.5	16.6	16.6	0.0
Mackle et al., 1997	Full	NZ	16.3	13.3	13.3	0.0
			20.0	14.4	10.6	3.8
Carruthers and Bryant, 1983	Early	NZ	21.9	14.1	14.1	0.0
			22.4	15.0	13.9	1.1
Mayne et al., 1988	Mid	N IRE	24.4	14.5	14.5	0.0

[1]Early = Cows pastured during early lactation, Full = cows pastured for the full lactation, Mid = cows pastured during midlactation. Those studies that do not have a specific DIM value did not supply the information in the study.

[2]US = United States; NZ = New Zealand; AUS = Australia; N IRE = Northern Ireland.

els, and fertilizer was required to maintain a long-term balance.

For the CONF operation with corn and alfalfa crops, the quantity and type of feeds produced were vastly different from that of the grazing systems (Table 6). With only 122 animals (cows and heifers) on the farm, considerable excess forage was sold. The amount of manure handled was high relative to the grazing operations. This manure was tilled into the soil before crop establishment, which led to a relatively low N volatilization loss. Nitrogen leaching loss was very high, though, due to the fall applied manure on fallow soil. Soil P and K maintained a long-term balance with this management strategy, which was associated with lower cow numbers and greater export of nutrients (forage) off the farm.

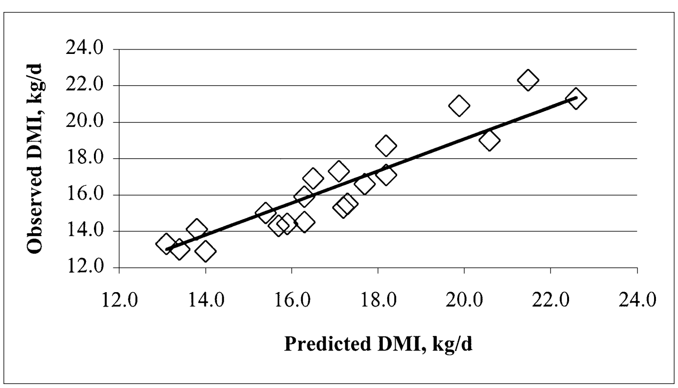

Figure 1. Relationship between observed and predicted DMI (Y = –0.614 + 0.9996X; SE = 0.92; r^2 = 0.88). The line Y = X represents perfect agreement between predicted and observed DMI. Data were taken from Berzaghi et al. (1996), Carruthers et al. (1996), Grainger et al. (1989), Holden et al. (1994a, 1995), Kolver et al. (1999, 2000), Kolver and Muller (1998), Mackle et al. (1997), Mayne et al. (1988), Rippel (1995), and Robaina et al. (1998).

Machinery and storage costs increased a small amount as the amount of concentrate fed was increased on the grazing farm. For the CONF system, these costs were greater due to the harvest, storage, and handling of more feed and manure (Table 6). Labor requirements were slightly lower for the CONF system, related to lower cow numbers, even though labor per cow was higher for the CONF than the grazing systems. The grazing systems required less labor for machine operation and feeding than the CONF system, but additional labor was required for pasture management. Alfalfa and corn production in the CONF system increased the seed, fertilizer, and chemical costs. Property tax was also greater in the CONF system due to a greater investment in animal housing and physical facilities. Overall, both production costs and farm income decreased with the use of grazing. Costs dropped more than income, providing a net increase in profitability in the grazing systems over the CONF system. The risk or year-to-year variation in farm profit decreased as concentrate supplementation increased, and in all cases was lower for the grazing systems than the CONF system.

It is interesting to note that, in general, net return increased at a decreasing rate as level of supplementation increased and cow numbers declined. The increase in profit between NONE and LOW, LOW and MED, and MED and HI was $21,001, $9,557, and $3,898, respectively (Table 6), illustrating the law of diminishing returns.

Same cow numbers. In the second scenario, cow numbers were held constant across systems at 100 mature animals with 74 heifers, and total milk sold per farm was allowed to vary (Table 7). Again, as supplementation increased, the forage consumed by cows decreased as a result of the substitution effect of the concentrate supplement for forage. Consequently, less for-

Table 6. Effect of varying level of supplementation on milk production, annual feed production, feed use, nutrient balance, costs, and net return of a low-input grazing seasonal dairy farm[1] in central Pennsylvania with similar levels of income from milk sales per farm (approximately 625,000 kg of milk sold annually).

		Grazing farm[2] Supplement level				
Production or cost parameter	Units	NONE	LOW	MED	HI	CONF[3]
Number of cows	. . .	125	103	90	81	70
Number of replacement animals	. . .	89	76	66	60	52
Average milk production	kg/cow	5000	6068	6968	7700	9000
		Actual values	Difference from NONE Farm[4]			
Hay production	t DM	97	0	10	21	27
Silage production	t DM	194	(2)	35	56	37
Corn silage production	t DM	0	0	0	0	255
Corn grain production	t DM	0	0	0	0	64
Grazed forage consumed	t DM	397	(19)	(84)	(133)	0
Forage purchased	t DM	285	(168)	(283)	0	0
Forage sold	t DM	0	0	0	75	190
Concentrate purchased[5]	t DM	0	60	105	141	130
Manure handled	t	1128	(194)	(330)	(420)	2565
N volatilization loss	kg/ha	117	(18)	(33)	(44)	(60)
N leaching loss	kg/ha	21	(1)	(2)	(3)	24
P accumulation	kg/ha	3	(5)	(9)	(10)	(2)
K accumulation	kg/ha	71	(52)	(92)	(124)	(114)
Field and feeding machinery cost	$	25,147	149	166	328	19,622
Fuel and electric cost	$	2136	(156)	(77)	(72)	1831
Feed, manure, machinery storage cost	$	9503	(33)	683	1101	8224
Labor cost	$	30,284	(3846)	(5521)	(6801)	(8827)
Seed, fertilizer, and chemical cost	$	9105	73	499	1143	1780
Grain drying cost	$	0	0	0	0	615
Land charge	$	10,008	0	0	0	0
Purchased feed and bedding cost	$	41,730	(14,878)	(21,051)	(20,034)	(7935)
Animal and milking facilities cost	$	31,259	(208)	(363)	(425)	12,140
Livestock expenses	$	31,131	(6102)	(9093)	(11,448)	(14,121)
Milk hauling and marketing fees	$	13,780	(5)	42	(33)	108
Property tax	$	823	(12)	(20)	(24)	1119
Total production cost	$	204,907	(25,317)	(34,735)	(36,266)	14,554
Milk, feed, and animal sale income	$	224,192	(4316)	(4177)	(1810)	2524
Net return to management (loss)	$	19,285	21,001	30,558	34,456	(12,030)
Standard deviation in net return	$	11,416	(1292)	(2802)	(3648)	1269

[1]81 ha of crop or grassland on a shallow loam soil simulated over 25 yr of State College, Pennsylvania weather.

[2]NONE = No supplement; LOW = 3 kg of DM/cow maximum supplement; MED = 6 kg of DM/cow maximum supplement; HIGH = 9 kg of DM/cow maximum supplement. All land is maintained in perennial orchardgrass pasture. All animals are on pasture year round and maintained on a spring calving cycle.

[3]CONF = Confinement farm. Cropland consists of 40.5 ha each of corn and alfalfa. All animals are fed rations of hay, silage, grain, and protein supplements mixed to meet their nutrient requirements, and they are housed year round in a free-stall barn.

[4]Numbers in parentheses represent a decrease compared with the NONE farm.

[5]Supplement consisted of a corn-based concentrate pellet for the grazing farm and a combination of corn, soybean meal, and an undegradable protein source on the CONF farm.

Table 7. Effect of varying level of supplementation on milk production, annual feed production, feed use, nutrient balance, costs, and net return of a low-input grazing seasonal dairy farm[1] in central Pennsylvania with similar cow numbers (100 mature animals).

		Grazing farm[2] Supplement level				
Production or cost parameter	Units	NONE	LOW	MED	HI	CONF[3]
Number of cows	. . .	100	100	100	100	100
Number of replacement animals	. . .	74	74	74	74	74
Average milk production	kg/cow	5000	6068	6968	7700	9000
		Actual values	Difference from NONE Farm[4]			
Hay production	t DM	97	(1)	11	20	27
Silage production	t DM	192	(1)	38	61	39
Corn silage production	t DM	0	0	0	0	255
Corn grain production	t DM	0	0	0	0	66
Grazed forage consumed	t DM	375	(1)	(52)	(92)	0
Forage purchased	t DM	119	(20)	(53)	(75)	0
Forage sold	t DM	0	0	0	0	23
Concentrate purchased[5]	t DM	0	58	116	174	217
Manure handled	t	899	8	(6)	(22)	4431
N volatilization loss	kg/ha	96	1	(4)	(7)	(12)
N leaching loss	kg/ha	20	1	1	(1)	38
P accumulation	kg/ha	(7)	4	7	9	17
K accumulation	kg/ha	19	(6)	(15)	(26)	(12)
Field and feeding machinery cost	$	24,996	(18)	398	662	20,727
Fuel and electric cost	$	1974	(15)	169	276	2742
Feed, manure, machinery storage cost	$	9481	(15)	714	1162	8246
Labor cost	$	25,583	277	1175	1824	2766
Seed, fertilizer, and chemical cost	$	9337	(109)	(388)	(311)	628
Grain drying cost	$	0	0	0	0	640
Land charge	$	10,008	0	0	0	0
Purchased feed and bedding cost	$	18,794	5512	10,113	14,912	35,287
Animal and milking facilities cost	$	30,932	74	147	222	12,467
Livestock expenses	$	24,300	0	0	0	0
Milk hauling and marketing fees	$	11,024	2350	4334	5947	8816
Property tax	$	805	4	8	12	1137
Total production cost	$	167,235	8058	16,670	24,705	93,566
Milk, feed, and animal sale income	$	180,672	33,081	61,708	85,209	121,002
Net return to management (loss)	$	13,437	25,023	45,038	60,504	27,436
Standard deviation in net return	$	9991	(153)	(351)	(735)	2694

[1]81 ha of crop or grassland on a shallow loam soil simulated over 25 yr of State College, Pennsylvania weather.

[2]NONE = No supplement; LOW = 3 kg of DM/cow maximum supplement; MED = 6 kg of DM/cow maximum supplement; HIGH = 9 kg of DM/cow maximum supplement. All land is maintained in perennial orchardgrass pasture. All animals are on pasture year round and maintained on a spring calving cycle.

[3]CONF = Confinement farm. Cropland consists of 40.5 ha each of corn and alfalfa. All animals are fed rations of hay, silage, grain, and protein supplements mixed to meet their nutrient requirements, and they are housed year round in a free-stall barn.

[4]Numbers in parentheses represent a decrease compared with the NONE farm.

[5]Supplement consisted of a corn-based concentrate pellet for the grazing farm and a combination of corn, soybean meal, and an undegradable protein source on the CONF farm.

age was purchased as supplementation increased, suggesting that stocking rates could be increased on these farms, especially when supplements are available.

Manure production and handling decreased slightly as the feeding of the more digestible concentrate was increased and N losses decreased accordingly (Table 7). Nitrogen volatilization losses were particularly high with the high pasture diets due to the high levels of CP in the pasture. Excess RDP led to high levels of ammonia in excreted manure and urine. As greater amounts of feed concentrate were imported to the farm, soil P accumulation increased slightly.

With cow numbers held constant, net return to management increased with increasing supplementation and increased milk production per cow (Table 7). Cost of production increased with increased supplementation; however, income outpaced this increased cost, resulting in greater profit as supplementation level increased. The rate of increase in net return decreased as supplementation level increased. The increase in profit between NONE and LOW, LOW and MED, and MED and HI was $25,023, $20,015, and $15,466, respectively.

Stocking rate to match forage production. In the third scenario, the stocking rate on the farm was set so that forage consumed on the farm matched long-term annual forage production, to minimize selling or purchasing forage (Table 8). As level of supplementation increased, forage consumption per cow decreased; therefore, stocking rates were increased as supplementation level increased.

Manure production and handling increased as supplementation level increased, primarily due to the addition of animals on the farm with each successive level of supplementation (Table 8). As expected, manure handled on the CONF farm was much higher than any of the grazing systems due to the need to haul all manure from the CONF barn. Nitrogen volatilization increased

Table 8. Effect of varying level of supplementation on milk production, annual feed production, feed use, nutrient balance, costs, and net return of a dairy farm[1] in central Pennsylvania where cow numbers are matched with forage production.

		Grazing farm[2] Supplement level				
Production or cost parameter	Units	NONE	LOW	MED	HI	CONF[3]
Number of cows	. . .	69	84	90	100	105
Number of replacement animals	. . .	52	62	66	72	76
Average milk production	kg/cow	5000	6068	6968	7700	9000
		Actual values	Difference from NONE Farm[4]			
Hay production	t DM	84	16	23	60	(14)
Silage production	t DM	141	60	88	165	90
Corn silage production	t DM	0	0	0	0	255
Corn grain production	t DM	0	0	0	0	66
Grazed forage consumed	t DM	317	0	(4)	(96)	0
Concentrate purchased[5]	t DM	0	49	105	172	232
Manure handled	t	621	131	177	229	4951
N volatilization loss	kg/ha	68	13	16	14	20
N leaching loss	kg/ha	18	1	2	2	42
P accumulation	kg/ha	–13	2	7	14	24
K accumulation	kg/ha	–20	3	1	0	33
Field and feeding machinery cost	$	23,393	590	920	1996	21,447
Fuel and electric cost	$	1560	335	499	1004	3237
Feed, manure, machinery storage cost	$	8515	1119	1671	3135	9212
Labor cost	$	19,064	3864	5699	9247	10,341
Seed, fertilizer, and chemical cost	$	10,237	(276)	(636)	(919)	(272)
Grain drying and roasting cost	$	0	0	0	0	643
Land charge	$	10,008	0	0	0	0
Purchased feed and bedding cost	$	3887	8231	16,792	26,532	53,765
Animal and milking facilities cost	$	30,430	301	466	678	12,969
Livestock expenses	$	16,767	3645	5271	8373	9336
Milk hauling and marketing fees	$	7608	3627	6214	8926	13,224
Property tax	$	777	17	26	37	1165
Total production cost	$	133,246	21,454	26,922	59,011	135,068
Milk, feed, and animal sale income	$	126,952	55,082	93,063	133,903	187,293
Net return to management (loss)	$	(6294)	33,628	56,141	74,892	52,225
Standard deviation in net return	$	5145	2434	3469	4396	9694

[1]81 ha of crop or grassland on a shallow loam soil simulated over 25 yr of State College, Pennsylvania weather.

[2]NONE = No supplement; LOW = 3 kg of DM/cow maximum supplement; MED = 6 kg of DM/cow maximum supplement; HIGH = 9 kg of DM/cow maximum supplement. All land is maintained in perennial orchardgrass pasture. All animals are on pasture year round and maintained on a spring calving cycle.

[3]CONF = Confinement farm. Cropland consists of 40.5 ha each of corn and alfalfa. All animals are fed rations of hay, silage, grain, and protein supplements mixed to meet their nutrient requirements, and they are housed year round in a free-stall barn.

[4]Numbers in parentheses represent a decrease compared to the NONE farm.

[5]Supplement consisted of a corn-based concentrate pellet for the grazing farm and a combination of corn, soybean meal, and an undegradable protein source on the CONF farm.

Table 9. Effect of farm changes on the economic benefit of varying level of concentrate supplementation on a farm with 625,000 kg/farm milk output annually.

		Grazing farm supplement level		
		NONE	HI	CONF
Base farm				
Net return to management (loss), $	$	19,285	53,741	7255
N leaching	kg/ha	21	18	45
		Difference in net return to management from base farm above		
Change soil type to medium loam	$	1309	869	11,504[1]
N leaching	kg/ha	(8)	(7)	(19)
Increase milk production 10%	$	13,279	15,305	10,665
Increase concentrate price 20%	$	0	(3621)	(3935)
Increase culling rate and breeding costs	$	(1699)	(786)	N/A

[1]Fat was added to the ration at a rate of 1% of total DMI intake to meet milk production goal.

with increased supplementation level, again related to relative animal numbers. Nitrogen leaching remained relatively stable for the grazing systems, but was higher for the CONF system. Soil P and K maintained a long-term balance with this grazing management strategy in contrast to the CONF system where P and K accumulation occurred.

Net return to management increased as supplementation level increased, due primarily to the increased cow numbers and increased milk per cow (Table 8). Cost of production also increased with increased cow numbers, but once again the increase in income outpaced the increase in production costs to increase net return. As seen in the previous scenarios, rate of increase in net return decreased as supplementation level increased. The increase in profit between NONE and LOW, LOW and MED, and MED and HI was $33,628, $22,513, and $18,751, respectively.

The economic risk or year-to-year variation in net return varied slightly across the five systems for all scenarios, but in different ways. In the first (constant milk production per farm) and second (constant cow numbers) scenarios (Tables 6 and 7), economic risk decreased as supplementation level increased. This result suggests that the grazing system that fed no supplement had a higher risk because this 100% pasture based diet was more reliant on adequate rainfall to provide moisture for pasture growth. At the higher levels of supplementation, there was more cushion with the supplement. However, pasture utilization may not have been optimum in this scenario, suggesting that stocking density was too low. Also more forage was available than needed, which was sold in good pasture growth years and fed to the herd in poor pasture growth years. The highest risk occurred for the CONF feeding system because corn yields were quite variable on this relatively shallow soil.

In the third scenario (matching stocking rate with forage production), economic risk increased with increasing supplementation level (Table 8). Because all forage produced on the farm was utilized by the herd in the long term, years of decreased forage production (such as drought) increased economic risk as forage had to be purchased to meet animal needs.

Sensitivity Analysis

A final series of simulations was conducted to measure the influence of various farm characteristics or management changes on the economic benefit (increase or decrease in net return) received from varying levels of concentrate supplementation (Table 9). Changing the soil type to a medium clay loam improved water holding capacity and overall productivity of the soil. This change decreased N leaching and improved net return on both the grazing and CONF systems. Nitrogen leaching loss was reduced more on the CONF system where large amounts of manure N incorporated into the soil were less susceptible to leaching in the deeper soil profile. In addition, less N fertilization was required to maintain crop growth. Improving the soil type provided a greater increase in the profitability of the CONF farm than the grazing farms. This was a result of increases in alfalfa and corn silage yields of 15 and 24%, respectively, which were impacted more by soil type change than pasture yields.

When milk production was increased 10% to reflect greater potential yields from individual herds, net return to management increased for all systems, as was expected (Table 9). The impact on increase in net return was slightly greater for the HI system than for the NONE system. To obtain higher milk production levels in the CONF system, it was necessary to add fat to the ration of early lactation cows up to 1% of total DMI.

In implementing these changes to the CONF system, profits increased by $10,665 over the base farm.

Increasing concentrate prices by 20% to reflect potential increases in feed prices impacted the net return on both the HI grazing farm and the CONF farm, but this of course had no effect on the grazing farm where no concentrates were fed (Table 9). The reduction in net return of the HI grazing farm was comparable to the CONF farm, but the grazing system remained the more profitable operation.

Pasturing lactating dairy cows and/or limiting supplementation can present unique challenges to reproductive efficiency, particularly in a seasonal herd. In the final set of simulations, culling rate was increased to 40% in the grazing herds to account for cows that were not bred within the seasonal window, and breeding expenses were increased from $40/cow to $50/cow to reflect potential reproductive problems associated with lower BCS (Table 9). These changes decreased net return by $1699 and $786 annually in the NONE and HI systems, respectively. Increasing cull rates and breeding costs impacted the NONE system more than the supplemented cows because this farm had the highest cow numbers.

CONCLUSIONS

Increased levels of concentrate supplementation had a substantial impact on the profitability and nutrient balance of grazing dairy farms in Pennsylvania. Profit increased as supplementation level increased, but at a decreasing rate. In comparison to CONF feeding systems, the grazing systems had a higher profitability at the higher levels of supplementation. This was due to decreased input costs associated with the grazing systems. Even though income also decreased with grazing, the net result was greater profitability. Phosphorus balance was achieved at the lower cow numbers, but as cow numbers increased and purchased feeds increased, P accumulation in soil increased.

ACKNOWLEDGMENTS

Special thanks to C. U. Coiner, L. D. Muller, J. E. Delahoy, F. Bargo, and E. S. Kolver for their assistance with this manuscript.

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